

THE EFFECT OF ELECTRIC FIELDS
IN THE DETECTION OF THE LOW
OF WATER VAPOR AND OF A MECHANICAL

Thesis
E57

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Annapolis, Md.

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This investigation was conducted in the Laboratory of the Aeronautical Engineering Department.

University of Michigan, 1892. The requirements
for Master Degrees, by L. A. Williams and S. S. Parrott.

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Input and feedback impedances consist of equal resistors; for multiplication the desired ratio of feedback to input resistors are plugged into the amplifier circuit.

The amplifiers are connected to a power supply distribution panel by means of six-wire shielded cables. The two knobs shown on the chassis of the amplifier are used to balance the amplifier for zero direct current output prior to use in the computer circuit. The knobs are connected to two variable resistors associated with the 6X5 tube.

To balance a multiplying amplifier, the input is shorted to ground and equal resistors (one megohm) are plugged into the input and feedback circuits. By use of a multi-range direct current vacuum tube voltmeter connected between ground and the output, zero output is obtained by adjusting the two knobs.

The procedure for balancing an integrating amplifier is similar. With one megohm resistor and a ten megohm resistor in input and feedback impedances respectively, balance is obtained by adjusting the knobs for a constant output.

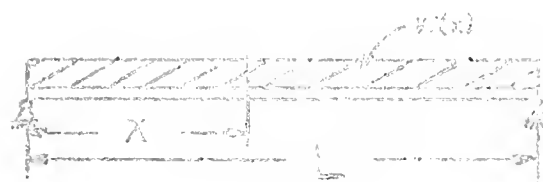
The procedures for balancing all amplifiers of amplifiers in a computer system will differ somewhat depending on the problem being solved.

$$2. \quad y(0) = 0 = y^0 = 0 \quad (4.1)$$

$$y'(0) = \text{shear} = 1 - 1.1 = -0.1$$

$$y'(max) \text{ from Fig. 11} = 0.946$$

3. Beam Fixed at $x = 0$ is



4. Conditions: Beam is fixed at $x = 0$

at $x = 0$, $y(0) = 0$ and $y'(0) = 0$

and $y'(L) = 0$

$$y(0) = y'(0) = 0 \quad (4.2)$$

Theoretical solution:

$$y(max) = \frac{1}{24} \frac{wL^4}{EI}$$

The computer equation is $y(max) = \frac{1}{24} \frac{wL^4}{EI}$

5. A change is necessary in the coordinate system

to be the change in the coordinate. The coordinate

change for the solution of the problem is

shown in Fig. 12. The end condition $y'(0) = 0$

is satisfied by shearing the beam at $x = 0$

and $y'(L) = 0$. There is a change in the

beam at the ends of the beam. The beam is

subjected to voltages $-V_a$ and V_b respectively

... $\Delta t = 0.01$... $\Delta t = 0.01$...
 ... before for $\Delta t = 0.01$...
 ... necessary in varying the ...
 ... obtain the proper end condition.

Fig. 13 shows the solution of the problem ...
 ... on the oscillograph. The length of the ...
 ... on the oscillograph is measured ...
 ... $L = 1.2$.

$$\frac{1}{2} \rho V^2 = \frac{1}{2} \rho V^2 = 1.1 \times 10^{-4}$$

$$\text{(from) theoretical } \rho V^2 = 1.30$$

$$\text{(from) from Fig. 13 } 1.15$$

The second preliminary problem is the ...
 ... of the first three small holes ...
 ... of a uniform force has been ...
 ... effects of bending (elasticity) ...
 ... considered loaded by ...
 ... and acceleration.

The differential equation of ...
 ... of such ...

$$\frac{\partial^2 u}{\partial x^2} = \mu \frac{\partial^2 u}{\partial t^2} \quad (1)$$

where $\mu = \frac{\rho}{E}$, the mass ...

ρ = the density of the material of the beam.

$\mu \frac{\partial^2}{\partial t^2}$ the inertial term, being

y = vertical displacement of the beam

x = distance along the beam measured from one end.

E = Young's modulus of the beam

A = Area moment of inertia of the

section of the beam with respect to

the central axis

It is assumed that $y(x,0) = 0$ and

where $K(x)$ is a function of x of the form

where $e^{j\omega t}$ represents the total oscillation of frequency ω .

and
$$\frac{\partial^2 y(x,t)}{\partial t^2} = -\omega^2 y(x,t)$$

and equation (3) becomes

$$E I \frac{d^4 K}{dx^4} - \mu \omega^2 K = 0$$

$$\text{or } \frac{E I}{\mu \omega^2} \frac{d^4 K}{dx^4} - K = 0$$

(4)

The computer equation is set up as follows. By making a change of the independent variable in the differential equation (4). The independent variable is changed to t , time in seconds, and the length of the beam is expressed as T , total elapsed time in seconds in seconds.

Then $x = \frac{L}{T} t$ and $\frac{d^n}{dx^n} = \frac{L^n}{T^n} \frac{d^n}{dt^n}$

The computer equation becomes

$$\frac{EI T^4}{\mu \omega^2 L^3} \frac{d^4 X}{dt^4} - X = 0 \tag{5}$$

For simplicity we let

$$\alpha_m^2 = \frac{\mu \omega_m^2 T^4}{EI}$$

$$\omega_m = \alpha_m \sqrt{\frac{EI}{\mu L^3}} \tag{6}$$

The delay of vibration for the n^{th} mode. In addition, for the computer equation (5) we have

$$C = \frac{T^4}{\alpha_m^2}$$

Thus the computer equation reduces to

$$C \frac{d^4 X}{dt^4} - X = 0 \tag{6}$$

In the computer solution, the C was given a value of unity (1 megohm) and the problem was solved by finding a length, T, on the oscillograph ribbon for which the simulated end conditions as determined by the beam supports were met.



The computer program for solving equation (6) is given in Fig. 1. The end conditions to be satisfied for a free beam are that the bending moment and shear force at each end are zero. These boundary conditions are expressed as

$$X''(0) = X''(L) = X'''(0) = X'''(L) = 0$$

To satisfy these end conditions on the computer, the feedback capacitors of A_1 and A_2 are initially shorted. As there is a definite but unknown slope and deflection at each end of the beam, they are simulated on the computer by battery voltages V_a and V_b respectively initially applied to the inputs of A_1 and A_2 . As before, V_b was fixed at 10 or 20 volts and $-V_a$ was varied for different solutions until the end conditions of zero bending force and bending moment were satisfied.

The outputs of A_1 and A_2 were connected through resistors to the two channels of the Kistler oscilloscope for recording oscillographs of X'' and X''' . Correct solutions showing the fulfillment of the end conditions required were obtained when the maximum of X'' , depending upon the ratio of the loads, passed through the zero axis. The X'' curve was used in measuring the length, T , of the deflection. This curve was used in preference to X''' because the X''' curve has a definite finite slope at the end of the solution.

Current solutions of the resonance problem. First three normal modes of vibration of the system were obtained in a manner similar to that previously described. V_b was made constant and $-V_a$ was initially set at an arbitrary value. All initial and boundary conditions were imposed by closing the initial condition voltage switches. The problem was started by simultaneously releasing all the end conditions. Several trial settings of the potentiometer controlling the voltage $-V_a$ were necessary before a correct solution for each mode was obtained.

Solutions of the same mode were quite readily obtained, but for the second and third modes the setting of the potentiometer controlling the voltage $-V_a$ was found to be very critical. This is due to slight instability of the amplifiers used and variations in power supply voltage were enough to cause a shift in position of solution. Many trials were necessary to obtain a few correct solutions. Fig. 11 shows the correct solution for the second mode obtained for the first three modes. The results obtained for ω_1 , ω_2 , and ω_3 checked very closely with those given in the Appendix of Don Hart's paper.

	Mode	Don Hart's	Present
ω_1	1	21.4	22.1
ω_2	2	61.7	62.70
ω_3	3	121.0	121.1

1. The power supply shall be of the type
which is required for the operation of the
equipment in the field. The power supply
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6. The power supply shall be of the type
which is required for the operation of the
equipment in the field. The power supply shall
be of the type which is required for the
operation of the equipment in the field.

and the synchronous motor, or the motor should be carefully selected. The motor should be effectively reduced by increasing the motor speed voltage received on the supply.

The potentiometer controlling the motor voltage. The three types of potentiometer were tested and found quite satisfactory for controlling the motor. To test the potentiometer, the motor was connected to the potentiometer.

It was felt that the potentiometer should be tested in the potentiometer and the potentiometer should be tested in the laboratory. The potentiometer should be tested on the potentiometer and the potentiometer should be tested on the potentiometer. The potentiometer should be tested on the potentiometer and the potentiometer should be tested on the potentiometer.

Part III

In the purpose of this study, the potentiometer is replaced by a potentiometer. The potentiometer is a device and its properties. The potentiometer is a device for the potentiometer. The potentiometer of this potentiometer has been described in the potentiometer. The effects of bending and shear deflection, inertia, external loading, damping force, and buoyancy

The first term

$$F_{\mu} = \frac{1}{2} \epsilon_{\mu\nu\lambda} F_{\nu\lambda}$$

of secondary infection.

$$\frac{\partial^2}{\partial x^2} \left[EI \frac{\partial^2 y(x,t)}{\partial x^2} \right] + \mu \frac{\partial^2 y(x,t)}{\partial t^2} = 0 \quad (13)$$

where μ = the mass distribution along the beam and includes the virtual mass which is an equivalent mass added to that of the ship to represent the inertia effect of the water associated with the ship's vibration.

For sinusoidal vibrations of frequency ω , it is assumed that $y(x,t) = X(x) e^{j\omega t}$ where $X(x)$ is a function only of x directed along the beam and is independent of time.

$e^{j\omega t}$ represents sinusoidal oscillations of frequency ω .

$$\text{i.e. } \frac{\partial^2}{\partial x^2} \left[EI \frac{\partial^2 y(x,t)}{\partial x^2} \right] = -\omega^2 e^{j\omega t} X(x)$$

and assuming that E is a constant and that I and μ are functions only of x along the beam, equation (13) becomes

$$\frac{d^2}{dx^2} \left[I \frac{d^2 X}{dx^2} \right] + \mu \omega^2 X = 0 \quad (14)$$

Let $I = I_0 f(x)$ and $\mu = \mu_0 g(x)$ where I_0 and μ_0 are maximum values of moment of inertia and mass respectively.

To set up the computer equation, a change in the independent variable is again necessary. Where x was the independent variable, let t , time in seconds

... of the ... (p ... the ... of the ship ... before, ...

In general,

$$\frac{d^m(t)}{dt^m} = \dots$$

... (C) ...

$$\frac{d}{dt} \left(\dots \right) = \dots$$

... the ...

... μ_0 ...

$$\frac{1}{\mu_0} \frac{d}{dt} \left[\frac{1(t)}{dt} \right] = \dots$$

$$\omega_n^2 = \frac{\mu_0 \omega_n^2}{\dots}$$

The natural frequency ...

$$\omega_n^2 = \frac{1}{\mu_0} \dots$$

The computer equation ...

$$\frac{d}{dt} \left[\frac{1(t)}{dt} \right] = \dots$$

In this computer ...

1. Model to g.	1.0	1.0
2.0		1.0

At the stepping relay 1-5-40-6, as originally planned, the length of rotation on the computer should have been $T = 10$ seconds. However, as the stepping relays were stopped the problem immediately upon reaching step 40, the length of the rotation, $T = 9.75$ seconds. This condition could have been corrected by rewiring the stepping relays' control relay circuit to provide for a quarter second pause on step 40 before the initial condition relays again imposed the end condition and stopped the motion. The authors of this paper did not feel at liberty to change the equipment in this manner, and felt that the quarter second lost could be accounted for in the solution knowing that T was actually 9.75 seconds. Even though the quarter second in the length of the computer solution meant ten feet in the length of the ship, this "lost" section of the bar does not materially affect the vibratory characteristics of the vessel.

Fig. 9 shows schematically the arrangement of the computer and complete network of controls and power supply. Fig. 8 is a photograph of the complete network. The outputs of A_2 and A_3 are then connected through amplifiers to the two channels of the Braun recorder for recording oscillographs of

$$x_1(t) \text{ and } \frac{d^2x_1}{dt^2}.$$

$$\begin{bmatrix} \frac{dx_1}{dt} \\ \frac{dx_2}{dt} \end{bmatrix}$$

of the form

$$u(x,y) = \sum_{n=0}^{\infty} a_n x^n y^n$$

where a_n are some constants.

Substituting this into (1)

we get the following equation for a_n

which can be written as

$$\sum_{n=0}^{\infty} a_n \frac{\partial^n}{\partial x^n} \left(\frac{\partial^n}{\partial y^n} \right) = 0$$

or

where δ_{nm} is the Kronecker delta.

Equating the coefficients of $x^n y^n$ to zero

we get the following recurrence relation

which is an approximation to the exact solution

where δ_{nm} is

$$\frac{\partial^n}{\partial x^n} \left[\frac{\partial^n}{\partial y^n} \left(\frac{\partial^n}{\partial x^n} \right) - \frac{1}{2} \left(\frac{\partial^n}{\partial x^n} \right) \frac{\partial^n}{\partial y^n} \right] = 0$$

which can be written as

where δ_{nm} is the Kronecker delta.

It is clear that the exact solution

$$\left(\frac{1}{E_0} + \frac{1}{E_1} \right)$$

where E_0 and E_1 are the moduli of the two media.

The displacement of the interface is denoted by u .

The constant C is determined by the boundary conditions.

$$B = \left(\frac{1}{E_0} + \frac{1}{E_1} \right)$$

where B is the bulk modulus of the system.

The displacement of the interface is denoted by u .

$$\left[\frac{1}{E_0} + \frac{1}{E_1} \right] \mu \omega^2 = \mu \omega^2$$

where μ is the mass density of the system.

The displacement of the interface is denoted by u .

The displacement of the interface is denoted by u .

The displacement of the interface is denoted by u .

The displacement of the interface is denoted by u .

where μ is the mass density of the system.

The displacement of the interface is denoted by u .

$$\frac{1}{\mu \omega^2} \left[\frac{1}{E_0} + \frac{1}{E_1} \right] \mu \omega^2 = \frac{1}{\mu \omega^2} \left[\frac{1}{E_0} + \frac{1}{E_1} \right] \mu \omega^2$$

(2.2)

$$\frac{1}{\mu \omega^2} \left[\frac{1}{E_0} + \frac{1}{E_1} \right] \mu \omega^2 = \frac{1}{\mu \omega^2} \left[\frac{1}{E_0} + \frac{1}{E_1} \right] \mu \omega^2$$

$$m \frac{d^2 x}{dt^2} + \frac{1}{2} \frac{d^2 x}{dt^2} + 24 \omega^2 x = 0 \quad (14)$$

$$+ \frac{1}{2} \frac{d^2}{dt^2} \left[i(t) \frac{d^2 x}{dt^2} \right] + 3 \frac{d^2}{dt^2} \left[i(t) x \right] = 0 \quad (15)$$

The natural frequency of the system is the

$$\omega_n = \sqrt{\frac{24 \omega^2}{m}}$$

In order to obtain the natural frequency of the system, it is necessary to reduce the circuit to a single loop. If the circuit is reduced to a single loop, the variables, $i(t)$ and $x(t)$, are reduced to a single variable, $i(t)$. The circuit can be reduced to a single loop by using the following representation for the circuit. The circuit is represented by the term $[i(t) x(t)]$ and the circuit is reduced to a single loop by the length of the circuit. The circuit is reduced to a single loop by the regrouping of components. The circuit is reduced to a single loop by the regrouping of components.

$$D = \frac{1}{2} \left[i(t) x(t) \right]$$

and the other equation becomes

$$m \frac{d^2}{dt^2} \left[i(t) \frac{d^2 x}{dt^2} \right] + D \frac{d^2 x}{dt^2} + 24 \omega^2 x = 0 \quad (16)$$

The conditions for the system are that the bending moment and shear are zero at both ends. In the previous problems discussed, there were two conditions at the second and third derivatives of the deflection, respectively. When in addition to bending deflection,

the bending moment and shear force are given by the following equations and shear force is given by

$$M = EI \left(\frac{\partial^2 y}{\partial x^2} + \frac{\mu \omega}{EI} y \right)$$

$$V = \frac{EI}{\mu \omega} \left[\frac{\partial^3 y}{\partial x^3} + \frac{\mu \omega}{EI} \frac{\partial y}{\partial x} + \frac{\mu \omega}{EI} \frac{\partial y}{\partial x} + \frac{\partial}{\partial x} \right]$$

where, in setting up the computer equation

the assumption was made that $\frac{\partial^2}{\partial t^2} \mu \omega \frac{\partial^2 y}{\partial x^2}$

is neglected for a good approximation of the

shear force and rotary inertia. Following the

assumption, the bending moment is proportional to

$\frac{\partial^2 y}{\partial x^2}$ and the shear is proportional to

$\frac{\partial}{\partial x} \left[\frac{\partial y}{\partial t} \right]$ in the computer equation (17)

The boundary conditions for the solution of the computer equation are then expressed as

$$i(c) \frac{\partial^2 y}{\partial x^2} = \frac{\partial}{\partial t} \left[i(c) \frac{\partial y}{\partial t} \right] = i(c) \frac{\partial^2 y}{\partial t^2} = \frac{\partial}{\partial t} \left[i(c) \frac{\partial y}{\partial t} \right] = 0$$

The computer circuit for the solution of equation (17) is given in Fig. 14, where the detector with resistance $6/0$ from the output of A_1 to the input of A_2 is included to accomplish the $\frac{\partial^2 y}{\partial t^2}$ term in the computer equation. The procedure for the ex-

relation (2) is used to determine the value of α . The solution of eq. (2) is $\alpha = 1$ and $\beta = 1$ and the only wave oscillation is added to the existing one. It is now necessary to determine the value of α which remains constant for all values of ω . The only value which has been found to be constant is $\alpha = 1$ instead of $6/9$ as in the case of the variable introduced as a feedback factor. The frequency from trial to trial is constant.

The oscillographs of the output voltage and the input voltage are given in Fig. 1 and 2 respectively.

It is found that the output voltage is constant in all cases to A_2 from A_1 and A_2 from A_1 and A_2 from A_1 to the output circuit in the range of 10^3 to 10^4 Hz. The alternative of using a feedback factor as mentioned above as an input to the output circuit is successful in stabilising the circuit and the output is used.

Theoretical solutions of the frequency of oscillation of vibration of the LNA 17 have been obtained by a calculator designed by Hill for harmonic and shear deformation and rotary inertia effects. The results are listed below.

Frequency of Vibration - Torsional

Bending and Shear Deformation and Torsion

No.	Computer		HEI
	θ	rad/sec.	rad/sec
1	7.00	11.29	10.28
2	1.615	23.62	19.77
3	0.705	35.00	30.03
4	0.457	46.80	36.80

The frequencies obtained by means of the analog computer when the effects of bending deformation and shear are considered are approximately 5% to 10% higher than the HEI values. The analog computer results are calculated directly from the differential equations and have not been corrected for any of power supply frequency variation. The latter is an important factor, especially in the torsional mode for better accuracy of results. Line frequency variation has an effect both on the measurement of θ on the recorder tape and on the balance of the operational amplifiers, necessary for reproduction of solutions.

Another source of error in the computer is the difference in the manner of the results line in the plotting relay and indicator panels used. Every circuit was able to have accurate resistance in each step for the calculation of mass and moment and inertia. However, the

many plug-in connections of resistors in stacks on the resistor panels introduced inaccuracies in the actual resistance obtained for each step. Then too, it is known that the bridging contacts of the stepping relays did not always perfectly bridge from one step to the next.

It is felt that the results were well within the accuracy of the computer network itself, and that corrections made to the oscillograph records as mentioned above would improve the precision of the values of frequencies of vibration obtained.

The results obtained when, in addition to bending deflection effect, an approximation to the effects of shear deflection and rotary inertia was considered are progressively higher, (from about ten percent for the first mode to about eighteen percent for the fourth mode) than those obtained by the IBM computer.

It is apparent that these deviations which increase with the higher modes result from something more than the inaccuracies in the computer network. The corrections made to approximate the effects of shear deflection and rotary inertia in setting up the computer equation were, in a large part, assumed for the increasing error. These assumptions were necessary to avoid complicating the present computer network to a degree out of proportion to the actual effect of shear and rotary inertia on the frequencies

rotation of the ship.

With a computer constructed in accordance with the above principles and suitable components, the product term $[f(t)g(t)]$ can be introduced as a variable. A network could be set up to solve a computer equation with inclusion of the term

$$\frac{\partial^2}{\partial t^2} \frac{I_{xx}}{IAC} \mu \frac{\partial^2 \psi(t, \theta)}{\partial t^2}.$$

The precision of the values of frequencies obtained from such an analog computer network should be significantly better than in the present instances.

CONCLUSIONS

Solutions to many engineering problems of practical interest involving higher order differential equations with variable coefficients may be obtained by means of a relatively simple and inexpensive electronic analog computer.

Solutions so obtained are well within the accuracy necessary for most engineering purposes.

The accuracy of solutions obtained are limited by the precision of the computer components used and regulation of the associated power supplies. The assumptions made in reducing an exact differential equation to a computer equation are in a large part necessitated by the precision

Economy of time and space which is the chief benefit of such an analog computer is discussed in this paper. With the necessary equipment available and having familiarity with the operating principles of systems of higher order differential equations, the analog coefficients would be a matter of a minute or so for a single operation.

The analog computer is especially adaptable to the solution of design problems where the study of the effects of varying design parameters may be required. Minimal effort by simple external changes to an analog computer network.

C A L C U L A T I O N

CALCULATION OF FREQUENCIES OF THE FIRST BENDING ONLY

Constants used:

$$I = 1.75 \text{ in.}^4 \quad T^2 = 95.0625 \text{ sec.}^2$$

$$\sqrt{\frac{EI_0}{M_0 L^4}} = \sqrt{\frac{1.75 \times 10^5 \times 2686}{2.006 \times 256 \times 10^6}} = 0.312$$

1st Mode

$$C = 6.0$$

$$\alpha_1 = \frac{T^2}{\sqrt{C}} = \frac{95.0625}{\sqrt{6.0}} = 38.85$$

$$\omega_1 = \alpha_1 \sqrt{\frac{EI_0}{M_0 L^4}} = 38.85 \times 0.312 \text{ rad./sec.}$$

$$\omega_1 = 12.1 \text{ rad./sec.}$$

2nd Mode

$$C = 0.98$$

$$\alpha_2 = \frac{T^2}{\sqrt{C}} = \frac{95.0625}{\sqrt{0.98}} = 95.1$$

$$\omega_2 = \alpha_2 \sqrt{\frac{EI_0}{M_0 L^4}} = 95.1 \times 0.312 \text{ rad./sec.}$$

$$\omega_2 = 29.6 \text{ rad./sec.}$$

3rd Mode

$$C = 0.23$$

$$\alpha_3 = \frac{T^2}{\sqrt{C}} = \frac{95.0625}{\sqrt{0.23}} = 190.125$$

$$\omega_3 = \alpha_3 \sqrt{\frac{EI_0}{M_0 L^4}} = 190.125 \times 0.312 \text{ rad./sec.}$$

$$\omega_3 = 60.6 \text{ rad./sec.}$$

$$\dot{\theta} = 0.15 \text{ rad/sec}$$

$$\dot{\theta} = 0.15 \text{ rad/sec}$$

$$\dot{\theta} = \frac{v}{r} = \frac{5.50}{0.25} = 22.0 \text{ rad/sec}$$

$$\dot{\theta}_2 = 0.15 \text{ rad/sec} = 0.0986 \text{ rad/sec}$$

$$\dot{\theta}_3 = 0.15 \text{ rad/sec}$$

$$\dot{\theta} = 0.15 \text{ rad/sec}$$

$$\dot{\theta} = 0.15 \text{ rad/sec}$$

$$\dot{\theta} = \frac{v}{r} = \frac{5.50}{0.25} = 22.0 \text{ rad/sec}$$

$$\dot{\theta}_4 = \frac{v}{r} = \frac{5.50}{0.25} = 22.0 \text{ rad/sec}$$

$$\dot{\theta}_5 = 0.15 \text{ rad/sec}$$

DATA FOR CALCULATION OF HIGHER MODES OF VERTICAL VIBRATION

L = 400 ft. E = 1.93×10^6 tons/ft.²

Section Stern To Bow	I ft. ⁴	$\frac{Tsec^2}{ft^2}$	K	A ft. ²	KAG tons
0-1	617	0.3115	0.345	3.55	1.215
1-2	1157	0.6773	0.271	7.15	1.434
2-3	1536	0.9025	0.220	9.30	1.576
3-4	1895	1.1300	0.171	12.29	1.791
4-5	2146	1.2946	0.153	14.48	1.922
5-6	2314	1.3548	0.141	16.45	2.079
6-7	2434	1.4568	0.136	18.41	2.237
7-8	2532	1.5493	0.131	20.42	2.415
8-9	2565	1.9540	0.116	22.44	2.737
9-10	2609	2.0060	0.111	24.45	2.958
10-11	2623	1.9101	0.137	26.65	3.249
11-12	2628	1.9159	0.134	28.71	3.542
12-13	2623	1.6765	0.141	30.97	3.836
13-14	2614	1.4242	0.152	33.49	4.115
14-15	2539	1.2439	0.166	36.19	4.342
15-16	2493	1.0137	0.186	39.50	4.782
16-17	2281	0.7112	0.205	43.00	5.235
17-18	1934	0.4483	0.223	46.34	5.711
18-19	1447	0.2546	0.246	50.00	6.211
19-20	711	0.2535	0.284	54.00	6.717

TABLE 1. 27A 37
 $i(t)$ and $\beta(t)$ in kilograms as Introduced into Capsule

$$I_0 = 2608 \text{ kg.}$$

$$M_0 = 2.0062 \text{ tons sec.}^2/\text{ft.}^2$$

$$I = I_0 i(t)$$

$$\beta = \beta_0 \beta(t)$$

Stern to Bow Section	$i(t)$	$\Delta R \text{ MEG}$ $\Delta i(t)$	$\Delta R \text{ MEG}$ Breakdown	$\beta(t)$	$\Delta R \text{ MEG}$ $\Delta \beta(t)$	$\Delta R \text{ MEG}$ Breakdown
0-1	0.235	0.235	.235	0.036	0.004	.16
1-2	0.139	0.204	.154 .046	0.315	0.027	.42
2-3	0.604	0.165	.133 .422	0.450	0.017	.35
3-4	0.720	0.116	.116 .045	0.513	0.015	.42
4-5	0.435	0.095	.050 .355	0.616	0.013	.35
5-6	0.330	0.073	.000 .330	0.676	0.010	.35
6-7	0.434	0.046	.046 .000	0.726	0.005	.35
7-8	0.333	0.029	.015 .000	0.770	0.006	.35
8-9	0.301	0.021	.001 .000	0.795	0.003	.35
9-10	0.278	0.009	.001 .000	0.800	0.001	.35
10-11	0.278	0.005	.004 .001	0.930	0.002	
11-12	1.000	0.002	.002	0.958	0.018	
12-13	1.000	0		0.896	0.112	
13-14	0.974	0.006		0.711	0.125	
14-15	0.830	0.005		0.621	0.030	
15-16	0.890	0.041		0.607	0.115	
16-17	0.713	0.030		0.375	0.135	
17-18	0.765	0.103		0.211	0.111	
18-19	0.572	0.192		0.121	0.111	
19-20	0.301	0.291		0.230	0.105	
$\Delta X = 20'$						

$$\frac{E}{KAG} = \frac{1}{A}, \quad A = \frac{20.7K}{E^2}, \quad B = \frac{1}{A} \left[\frac{1(t)}{\beta(t)} \right]$$

Section	$\frac{E}{KAG}$	$\frac{1}{A}$	$\frac{E}{KAG} + \frac{1}{A}$	$\frac{1(t)}{\beta(t)}$
0-1	1.511	0.187	1.698	0.024
1-2	1.291	0.140	1.431	0.137
2-3	1.222	0.107	1.329	0.272
3-4	1.190	0.081	1.271	0.435
4-5	1.188	0.071	1.259	0.546
5-6	1.222	0.073	1.295	0.600
6-7	1.140	0.073	1.213	0.677
7-8	1.124	0.072	1.196	0.735
8-9	1.111	0.069	1.180	0.787
9-10	1.163	0.067	1.230	0.813
10-11	1.247	0.068	1.315	0.815
11-12	1.250	0.067	1.317	0.825
12-13	1.111	0.062	1.173	0.856
13-14	1.062	0.065	1.127	0.746
14-15	1.147	0.077	1.224	0.611
15-16	1.076	0.090	1.166	0.461
16-17	1.033	0.085	1.118	0.342
17-18	1.097	0.076	1.173	0.211
18-19	1.279	0.125	1.404	0.076
19-20	1.430	0.182	1.612	0.016
		$\Sigma = 26.13$	$\Sigma = 10.47$	
		$E_{AVE} = 1.174$	$AVE = 0.555$	

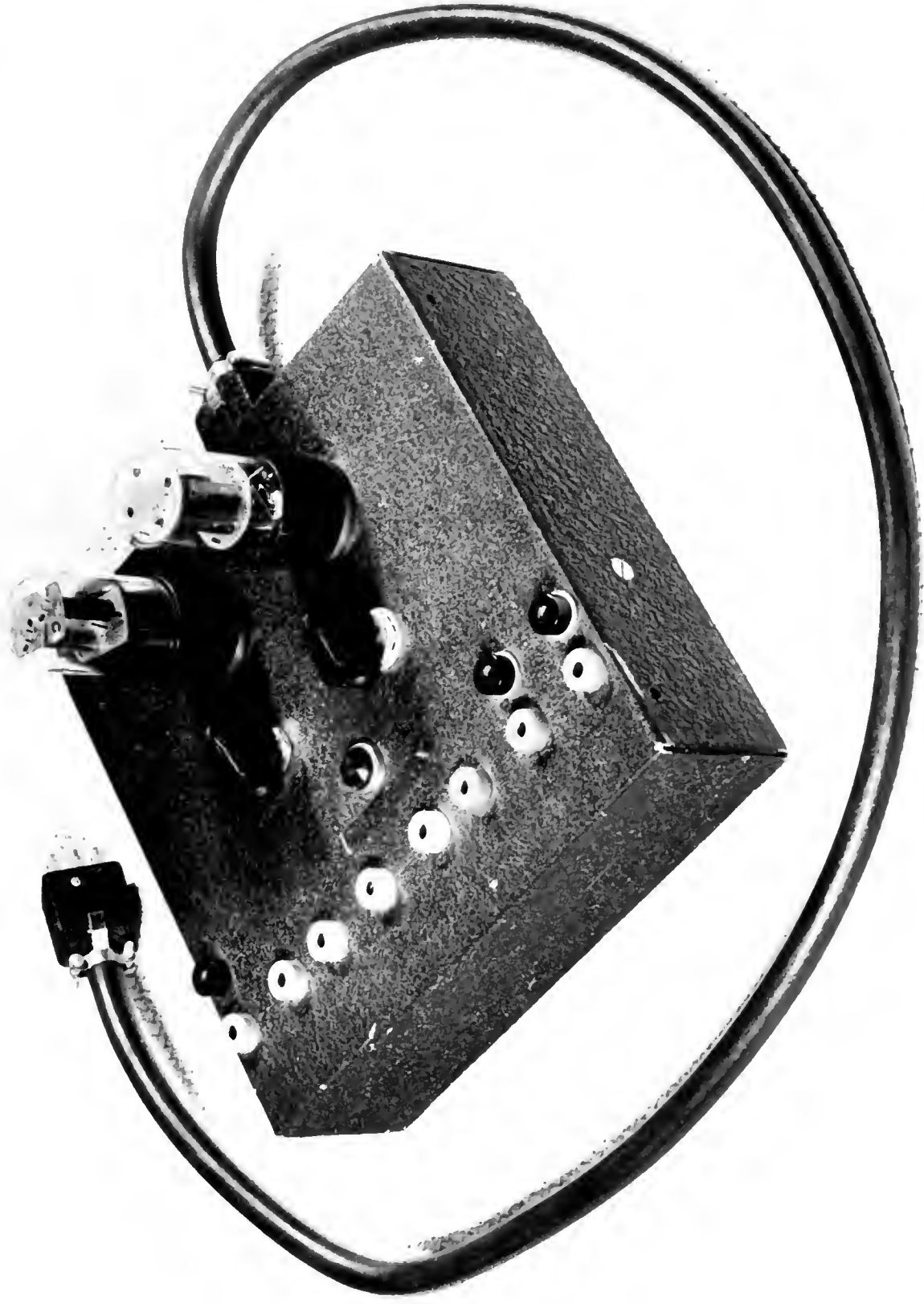
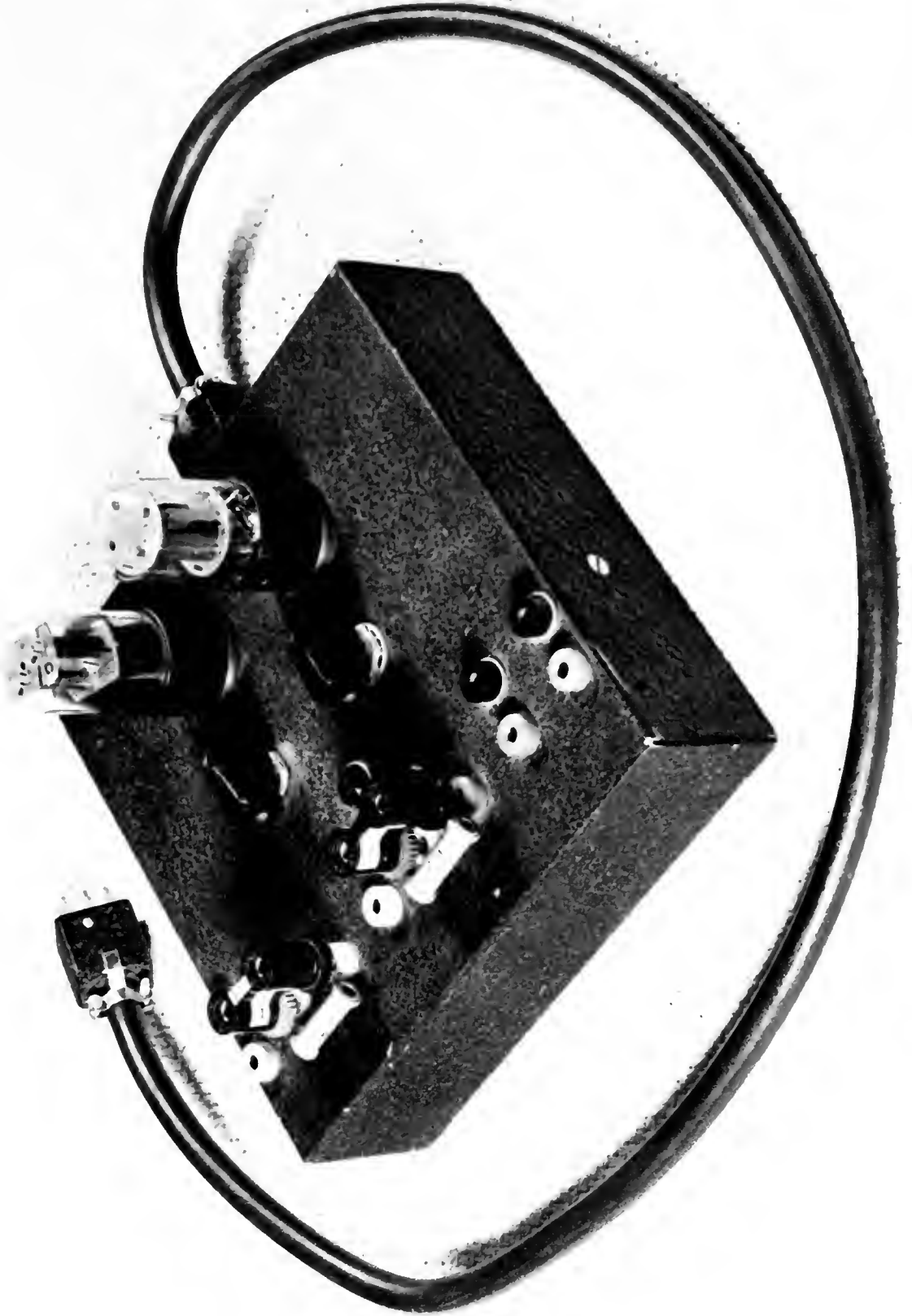


Figure 2 D. C. Amplifier Chassis

Figure 3
D.C. Amplifier Set Up as a Multiplier.



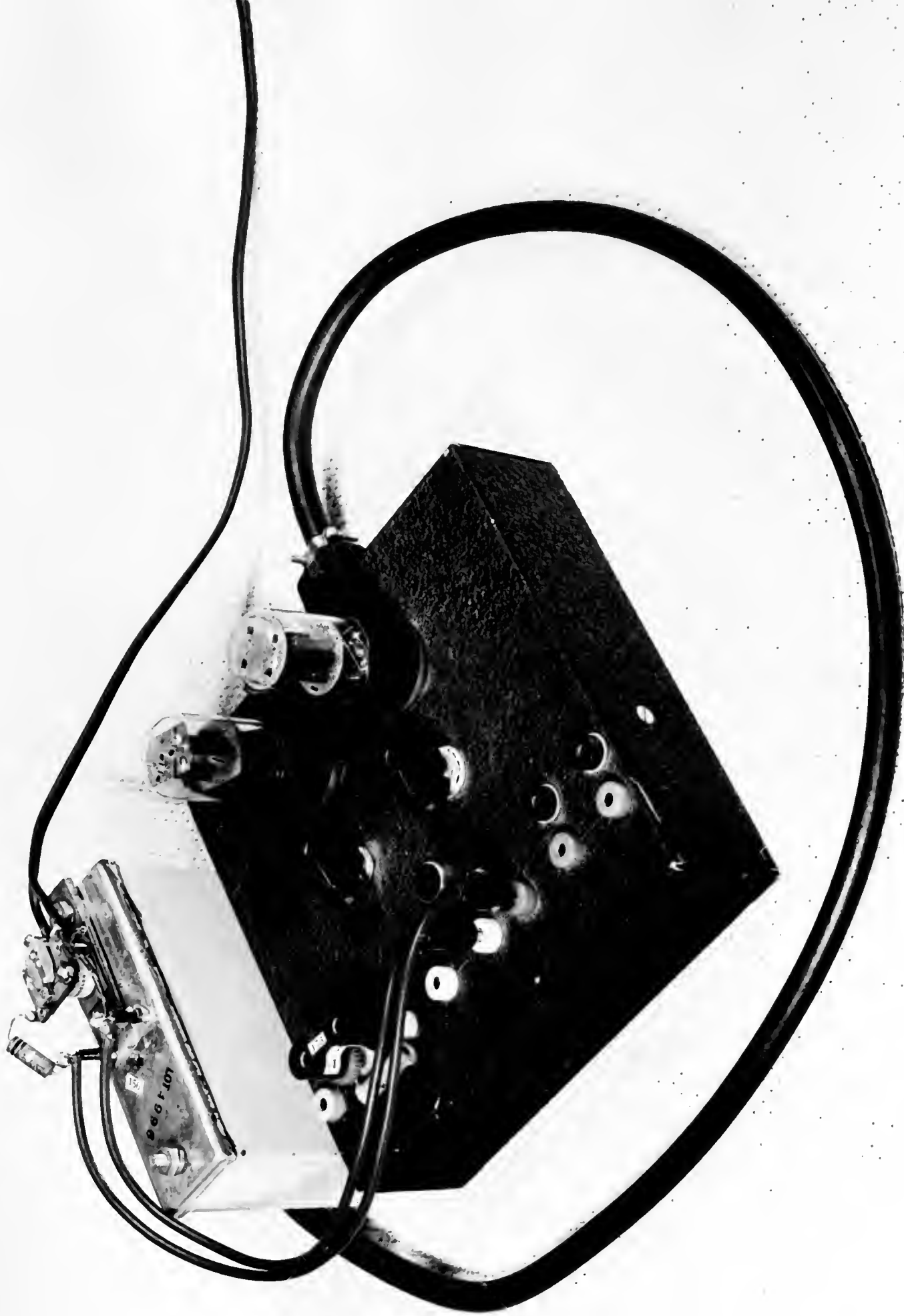


Figure 4 D. C. Amplifier Set Up as an Integrator

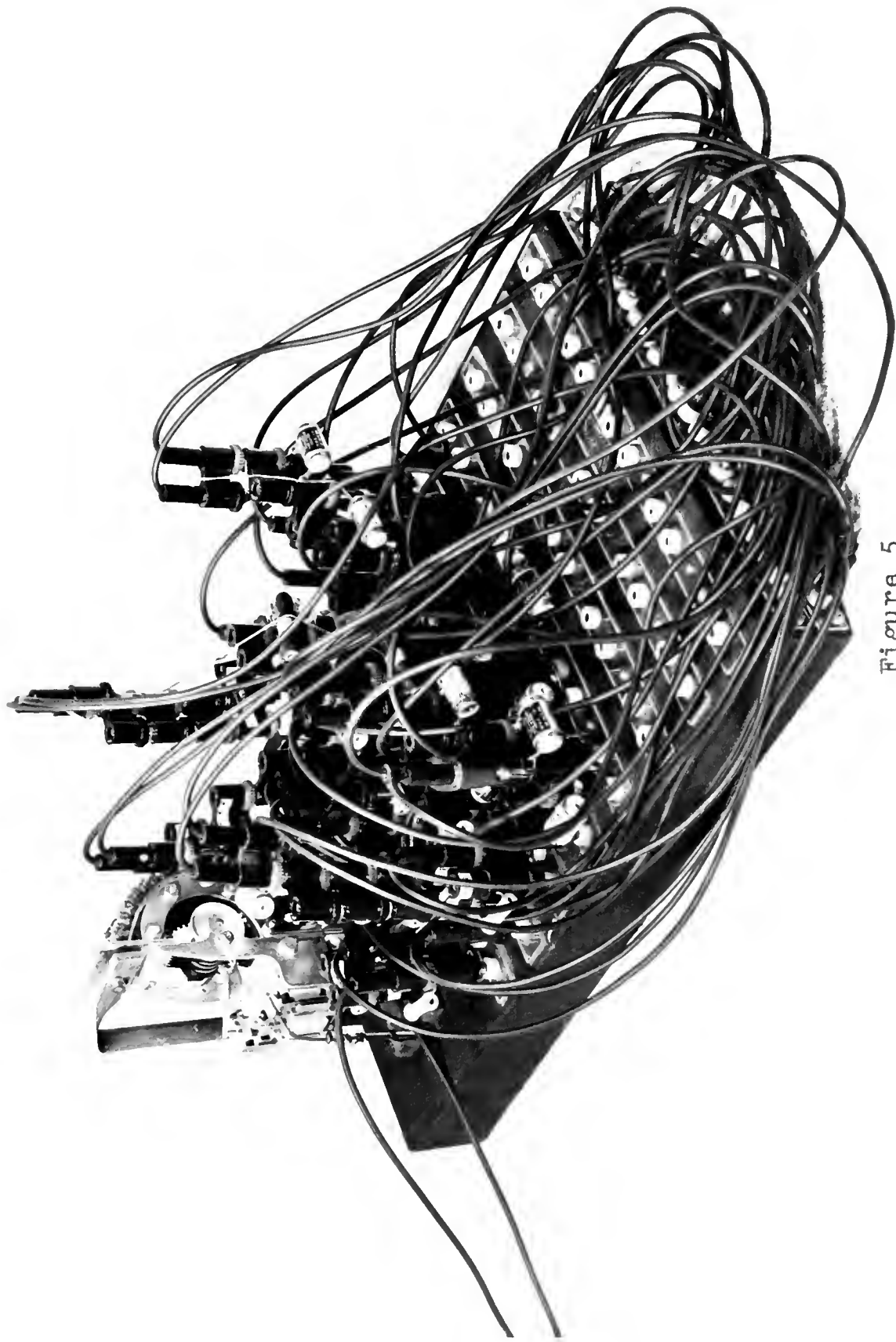
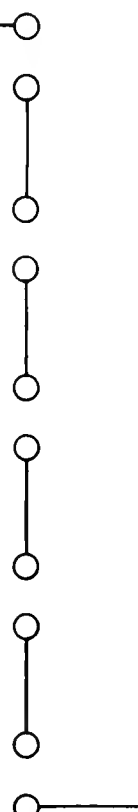
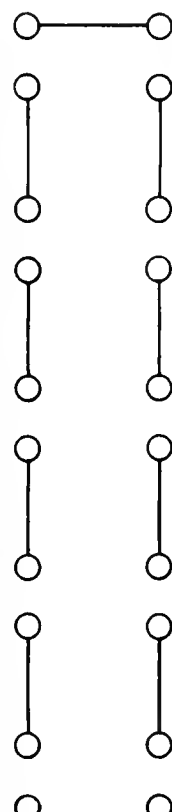
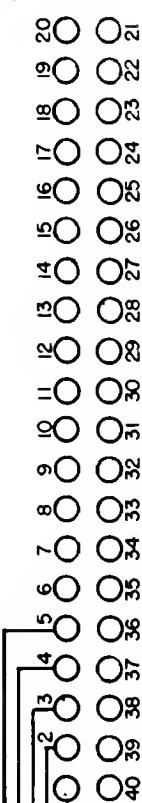


Figure 5

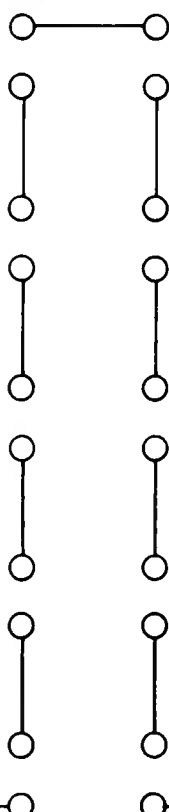
Stepping Relay and Resistor Panel Unit.

NOTE: JACKS 6-40 TO BE
CONNECTED SIMILARLY

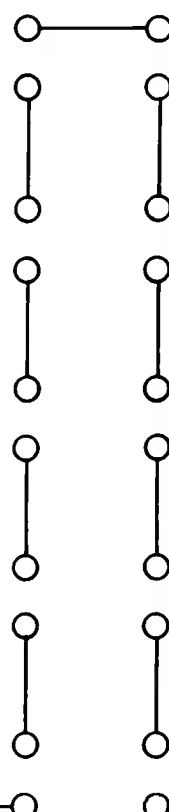
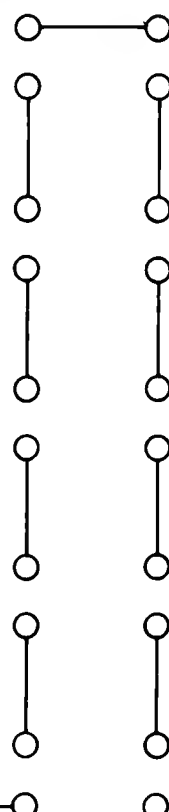
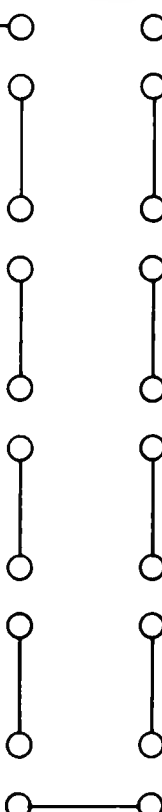
THESE JACKS CON-
NECTED TO CORRE-
SPONDING STEPPING
RELAY CONTACTS



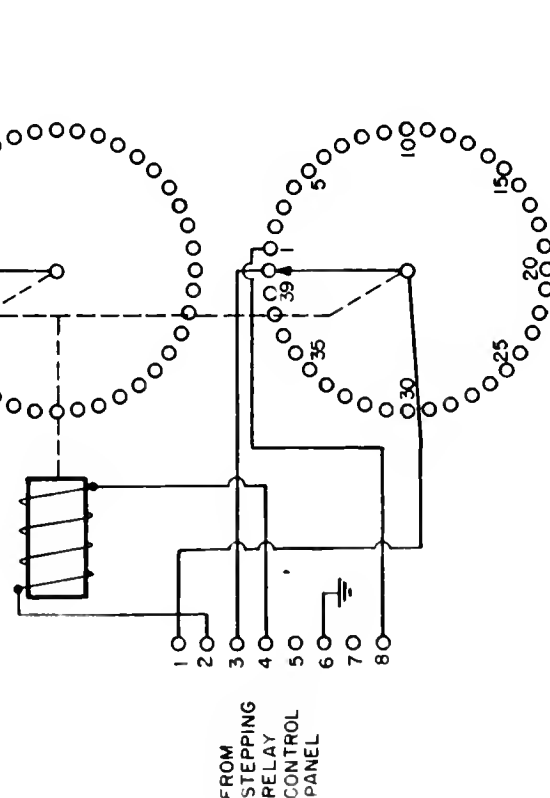
PLUG-IN
RESISTOR
JACKS



PATCH CORDS ARE
USED TO MAKE
CONNECTIONS TO
STEPPING RELAY
JACKS SHOWN
ABOVE

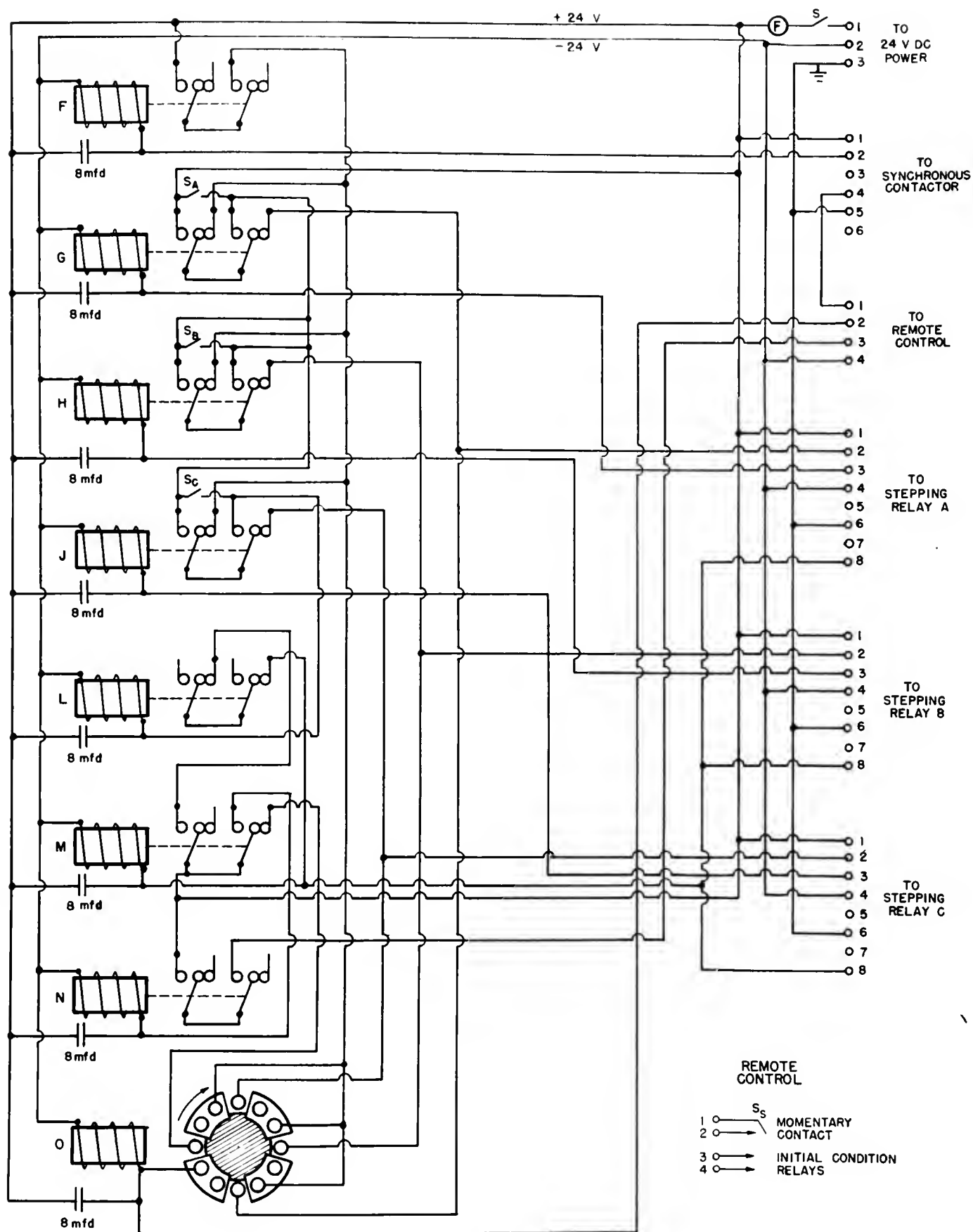


TO
OPERATIONAL
AMPLIFIER



FROM
STEPPING
RELAY
CONTROL
PANEL

Figure 6.
STEPPING RELAY AND PLUG-IN RESISTOR CIRCUIT

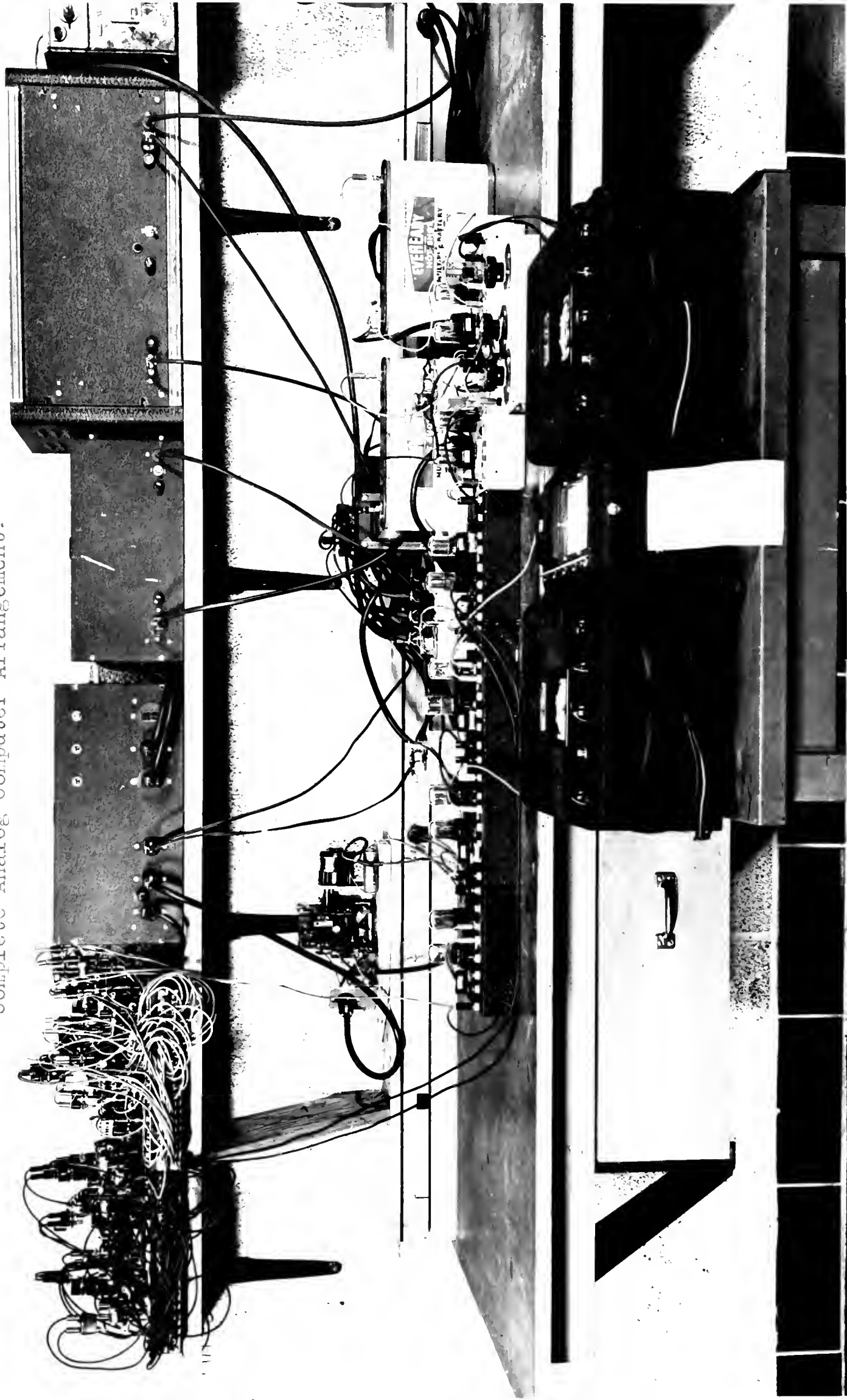


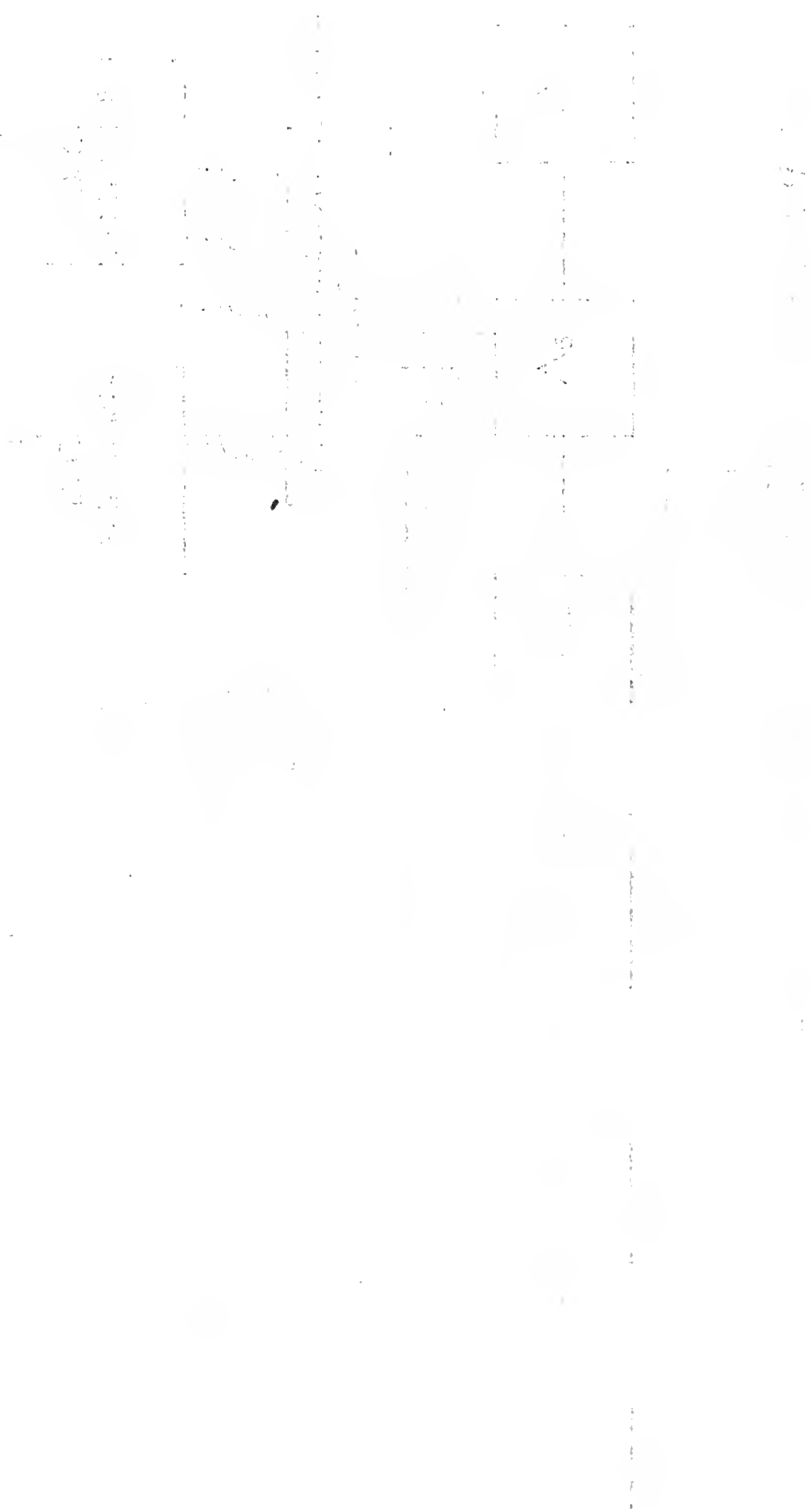
STEPPING RELAY CONTROL CIRCUIT

Figure 7

Figure 8.

Complete Analog Computer Arrangement.







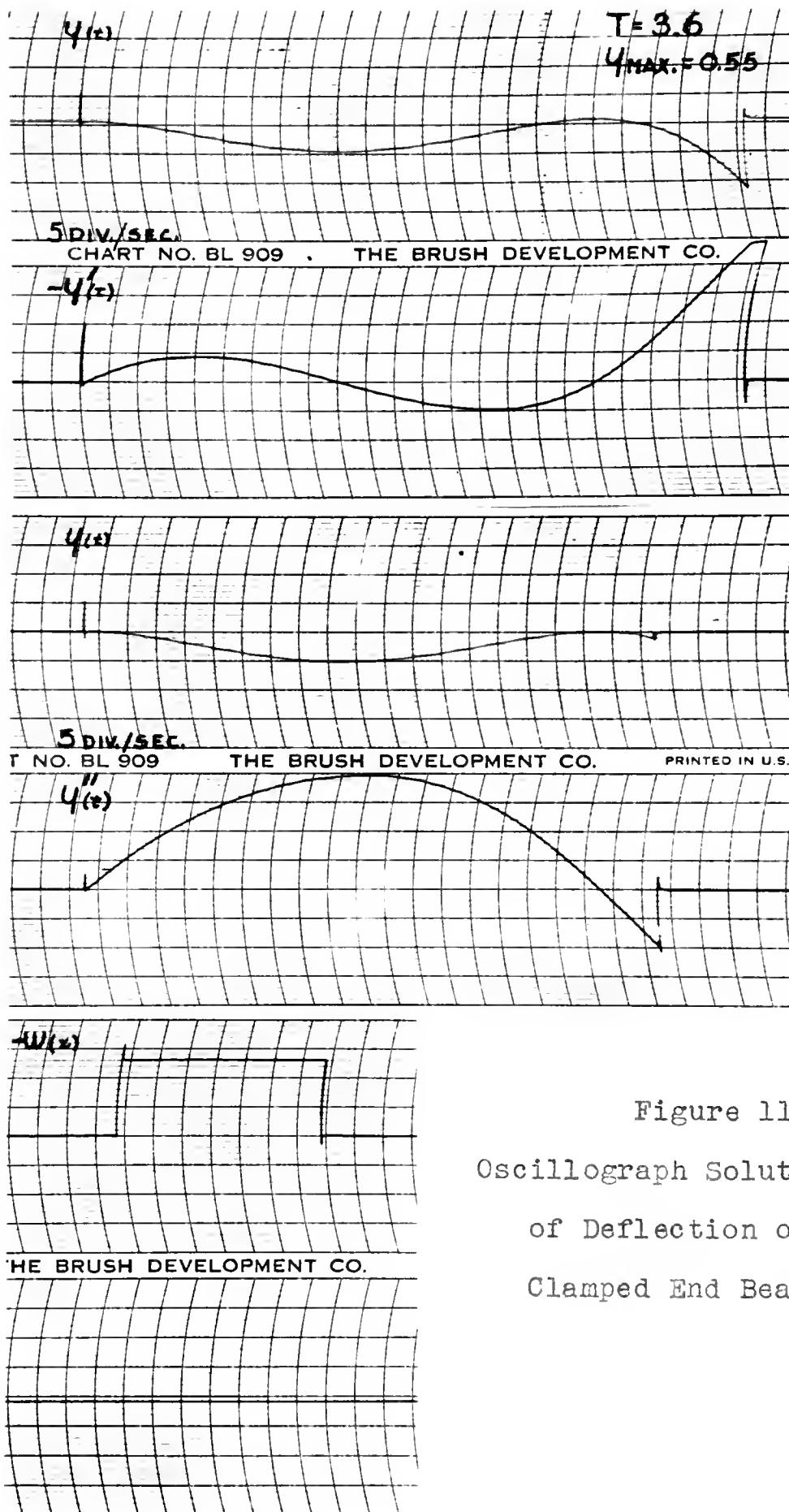


Figure 11
 Oscillograph Solutions
 of Deflection of
 Clamped End Beam.

1000



1000

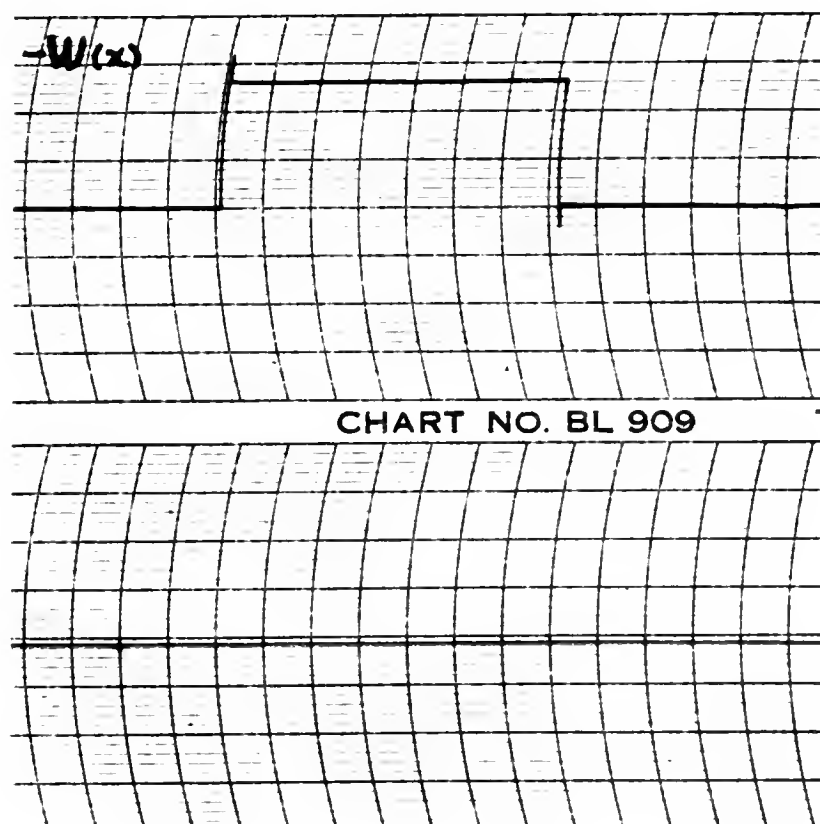
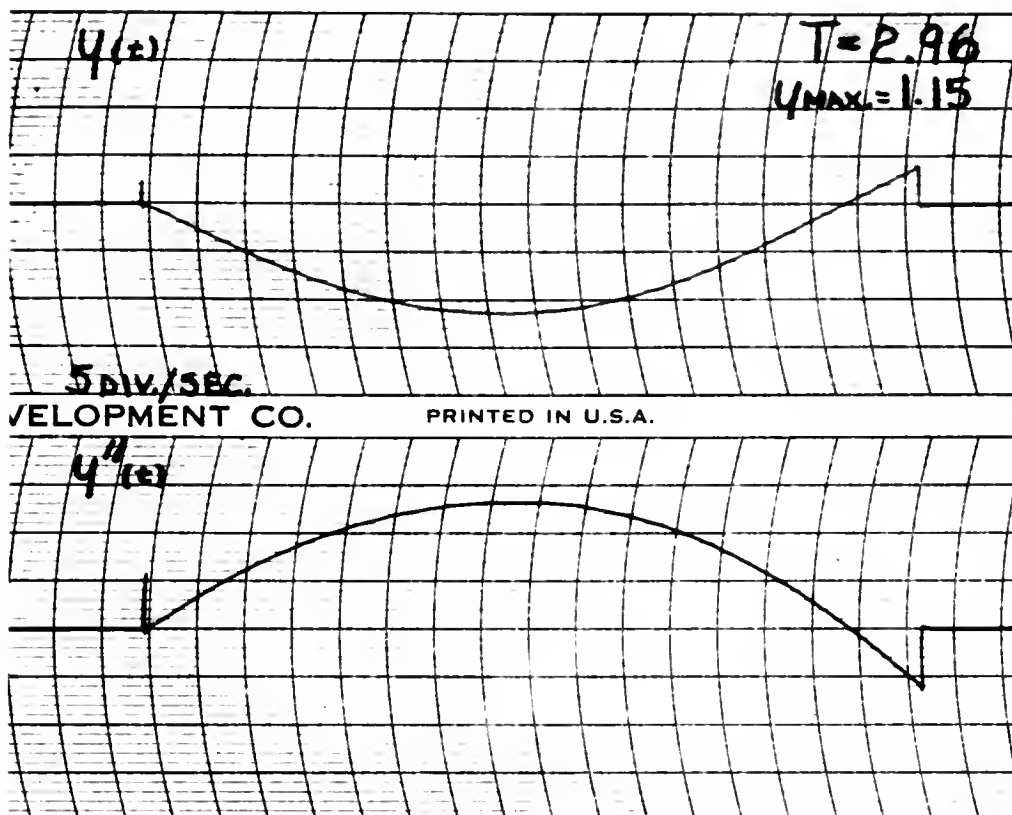


Figure 13

Oscillograph Solution of Deflection of Hinged End Beam.

3

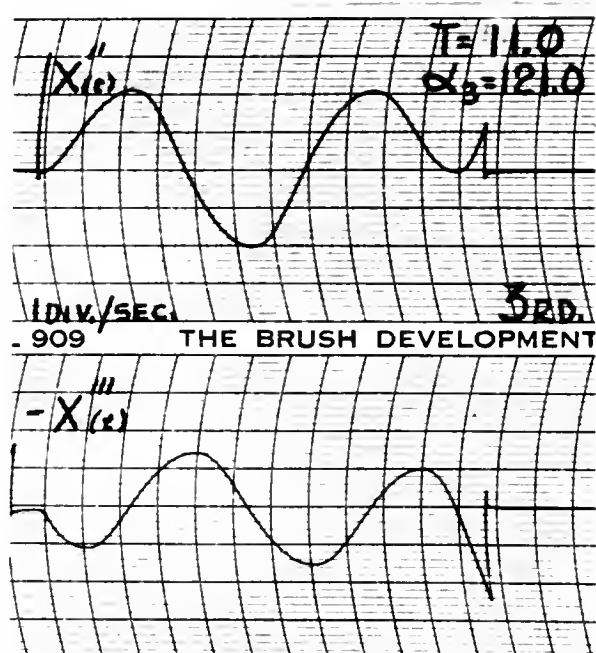
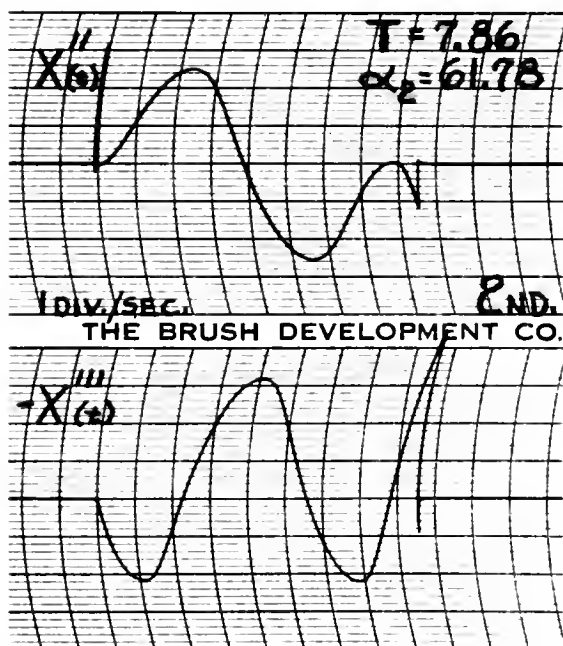
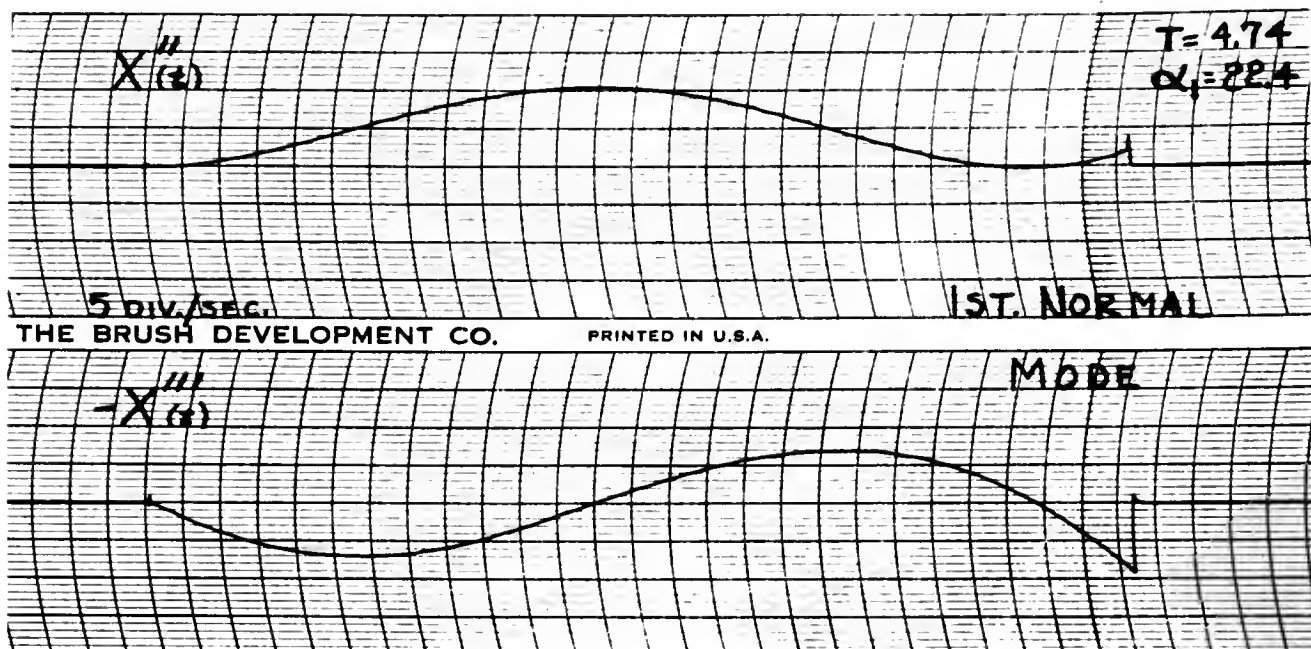
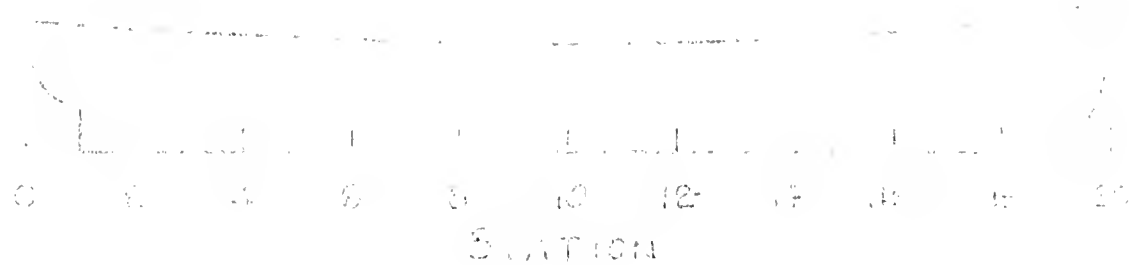


Figure 15

Oscillograph Solutions of First Three Normal Modes,
Uniform Free-free Beam.

2000-10-01





11 25 19 10
 10 10 10 10

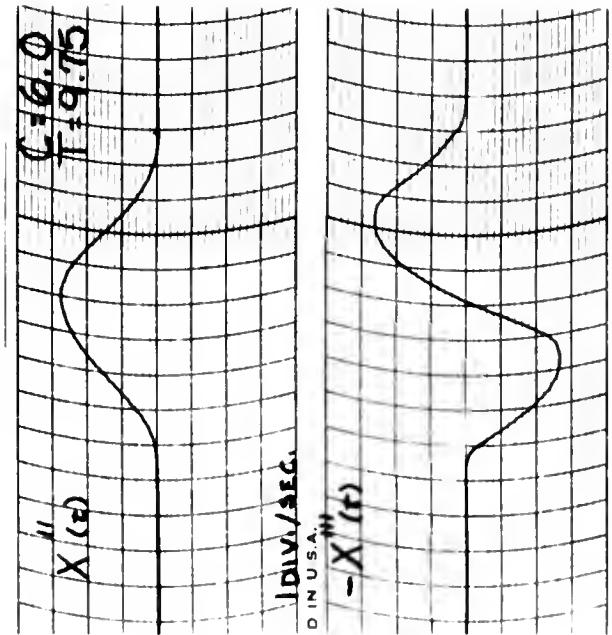
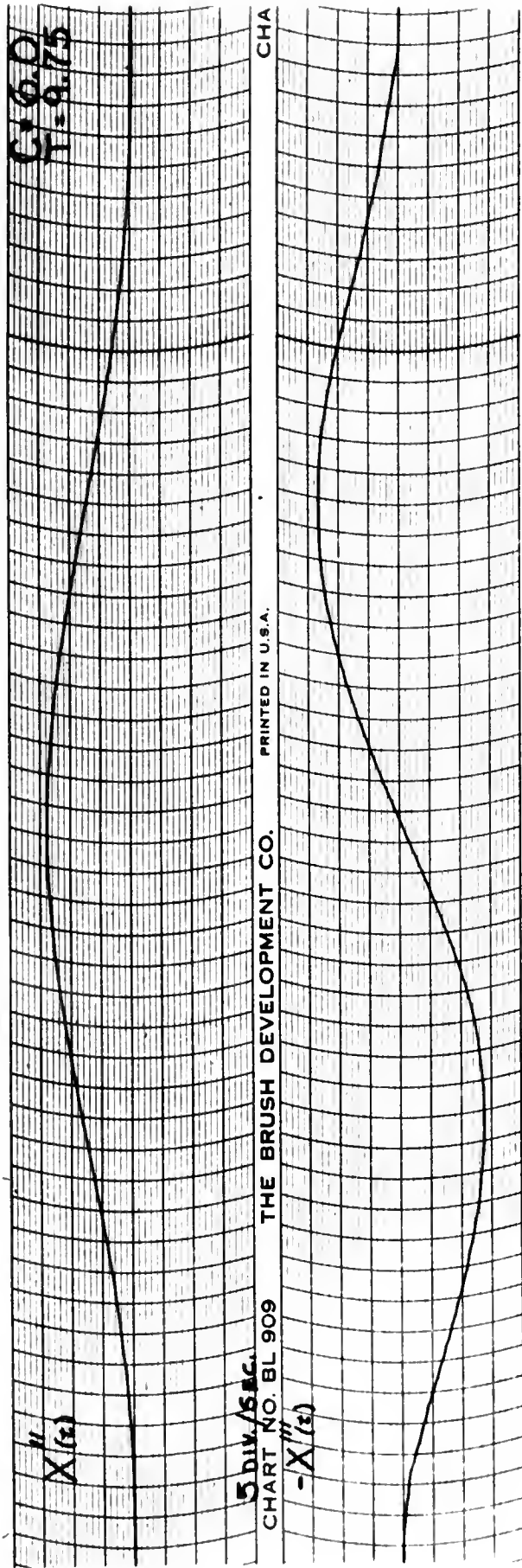


Figure 18

Oscillograph Solution of First Normal Mode

APA 87, Bending Deflections Only.

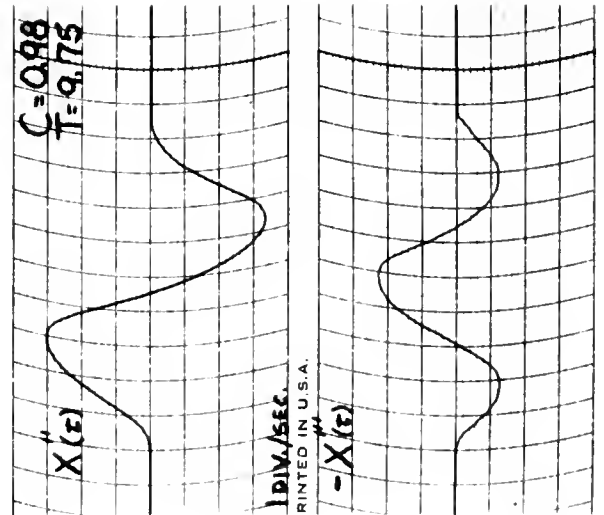
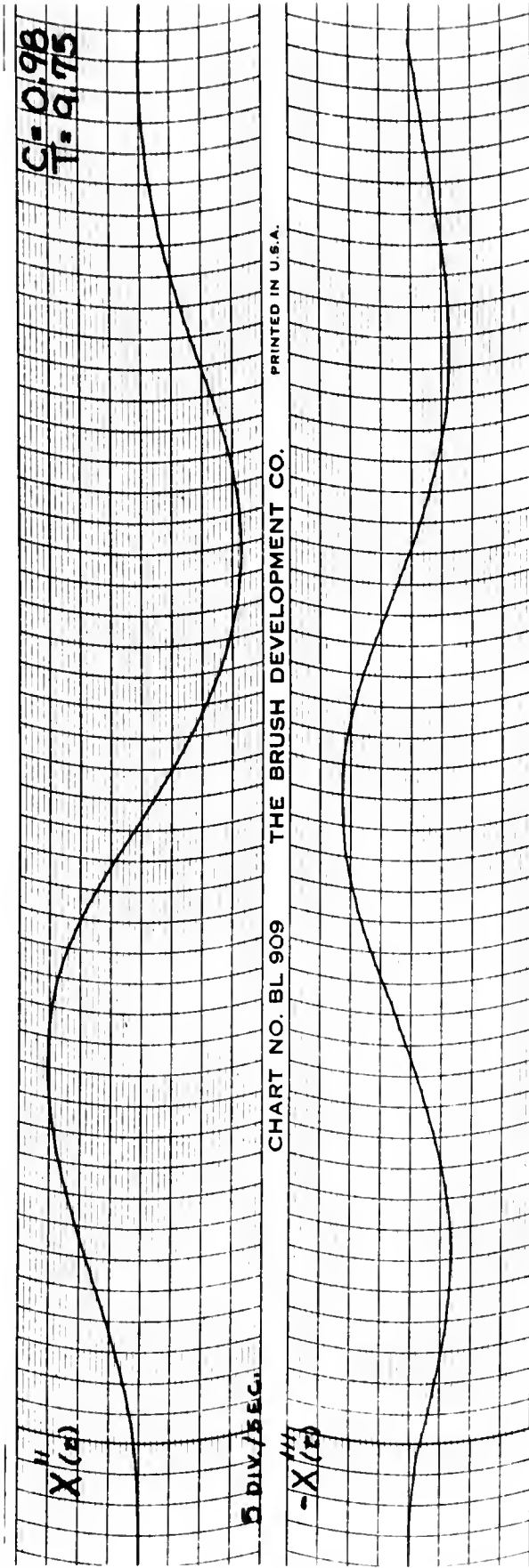


Figure 19

Oscilloscope Solutions of Second Normal Mode

APA 87, Bending Deflections Only

FIGURE 20

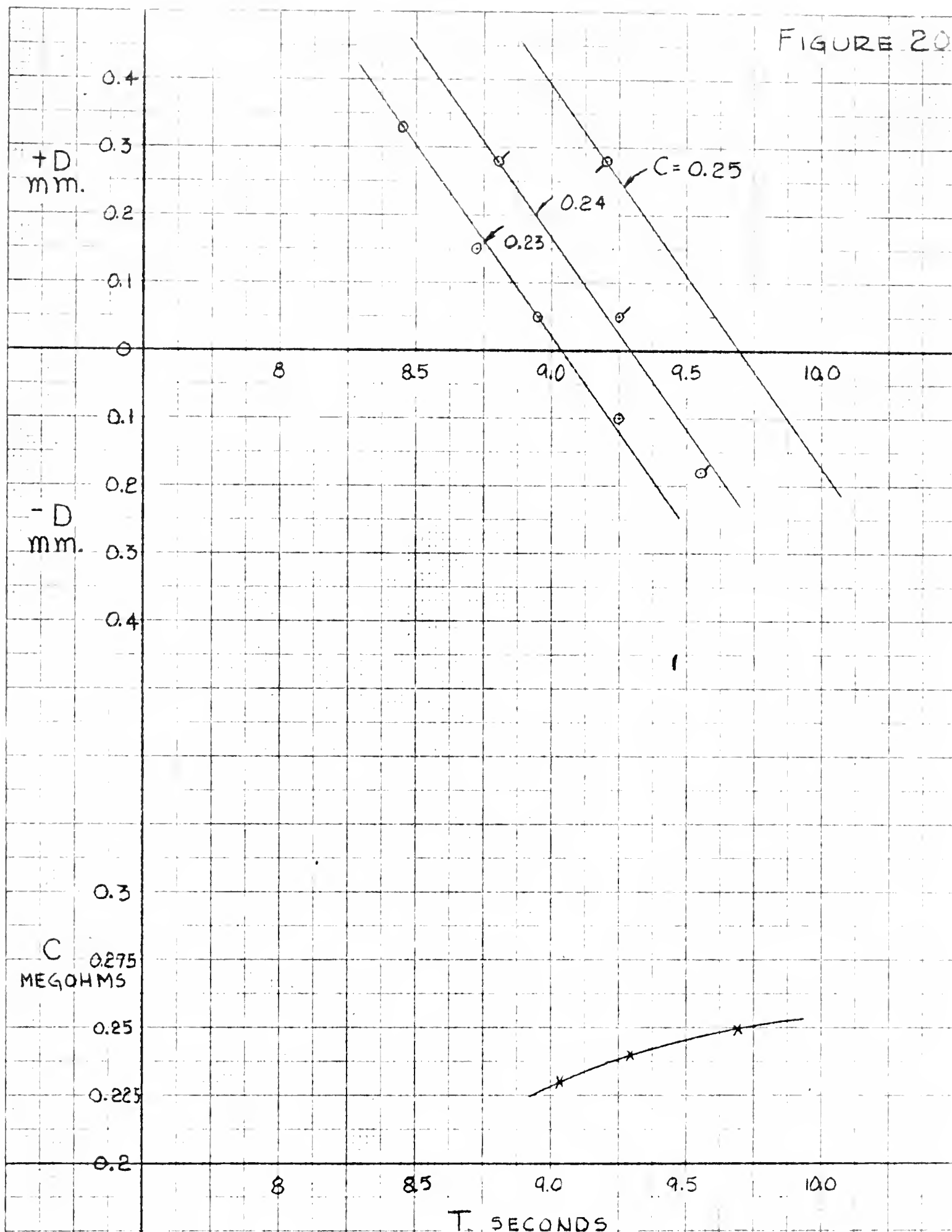


FIGURE 20

GRAPHICAL SOLUTION FROM OSCILLOGRAPH RECORDS
OF THIRD MODE, APA 87, BENDING DEFLECTIONS ONLY.

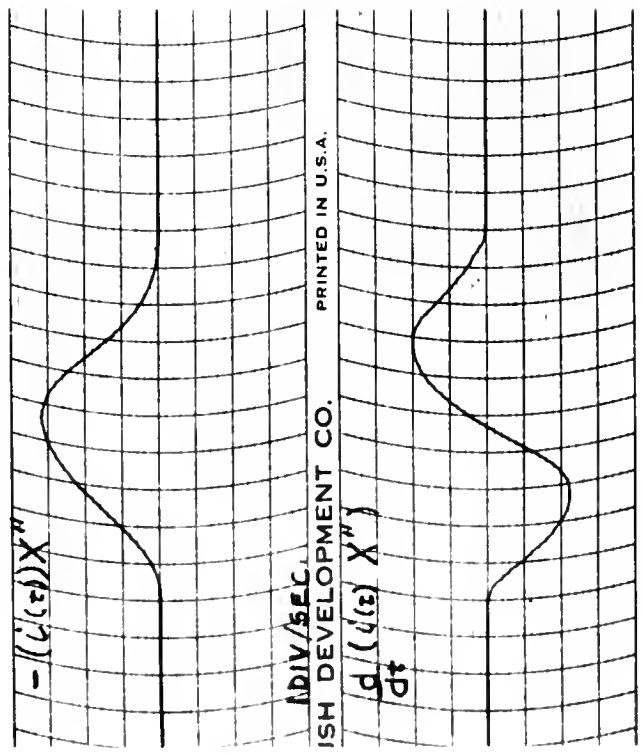
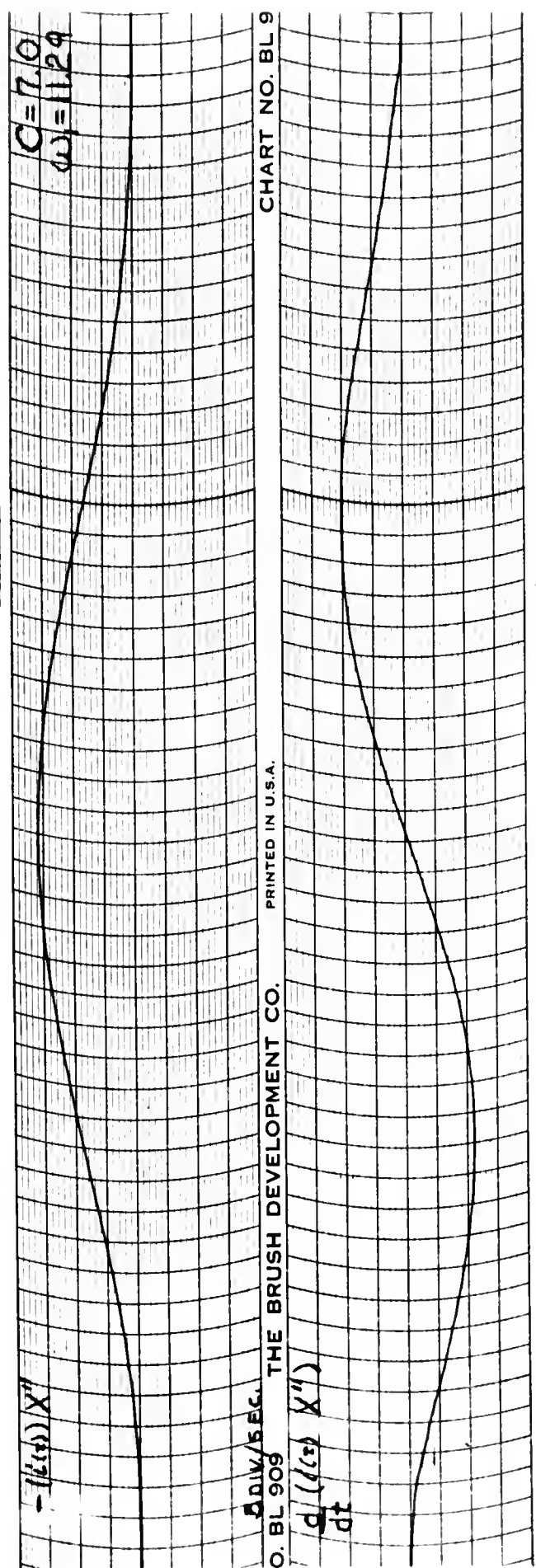


Figure 21

Oscilloscope Solution of First Normal Mode, APA 87, Bending and Shear Deflections and Rotary Inertia.

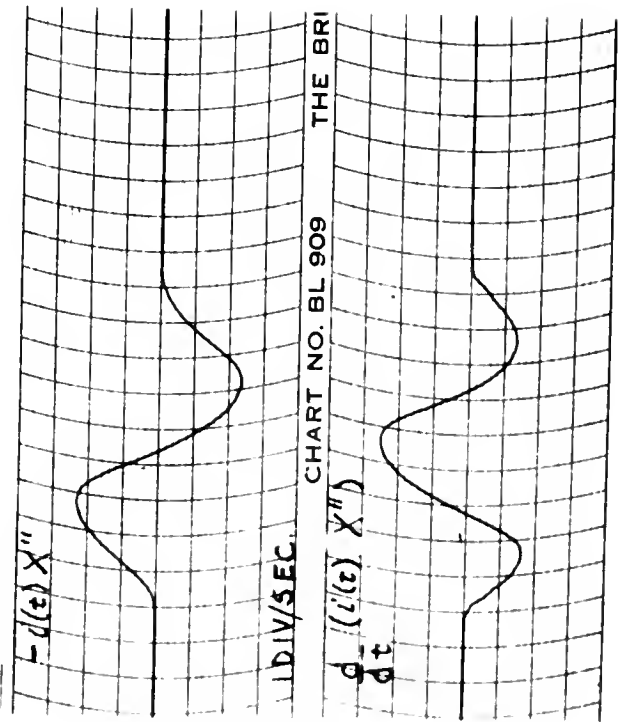
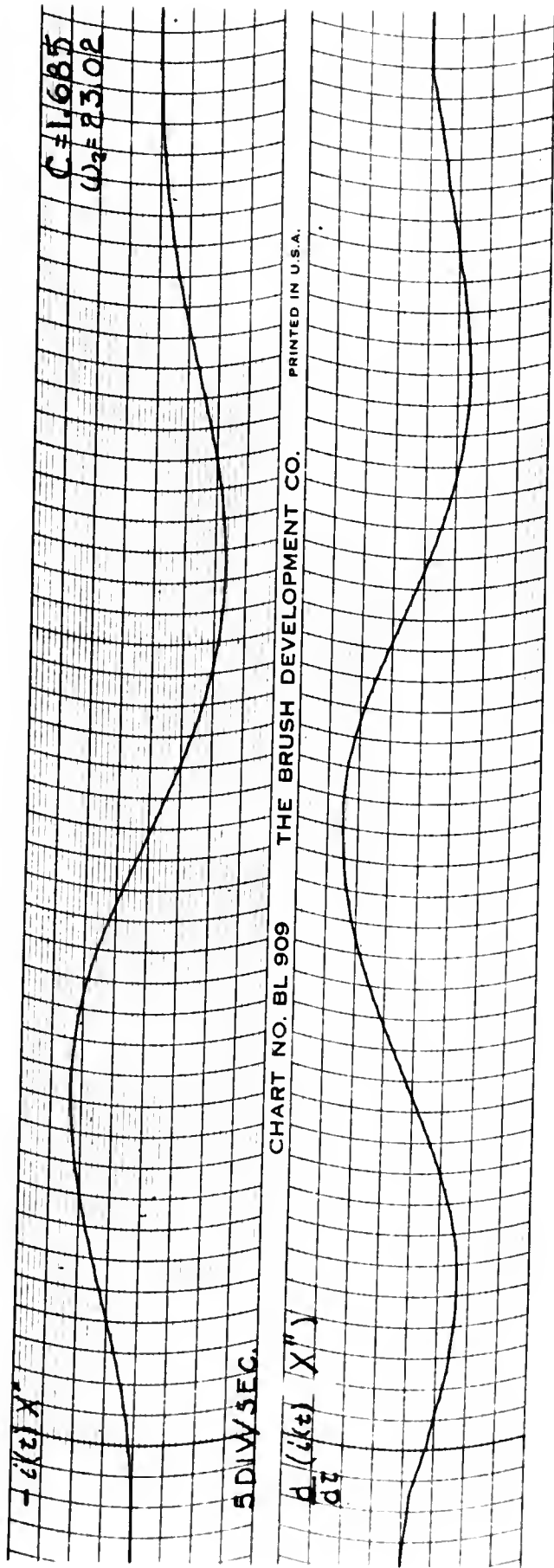


Figure 22

Oscilloscope Solution of Second Normal Mode, APA 37,
Bending and Shear Deflections and Rotary Inertia.

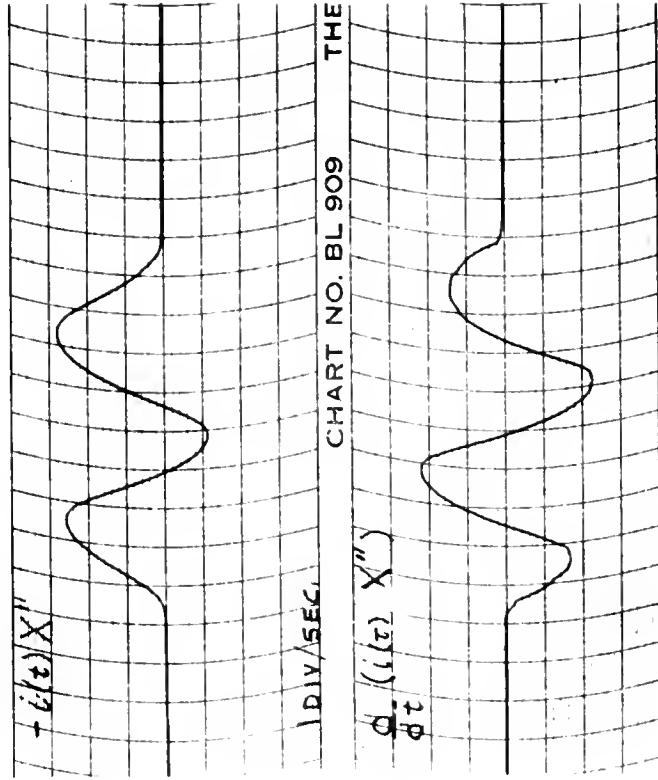
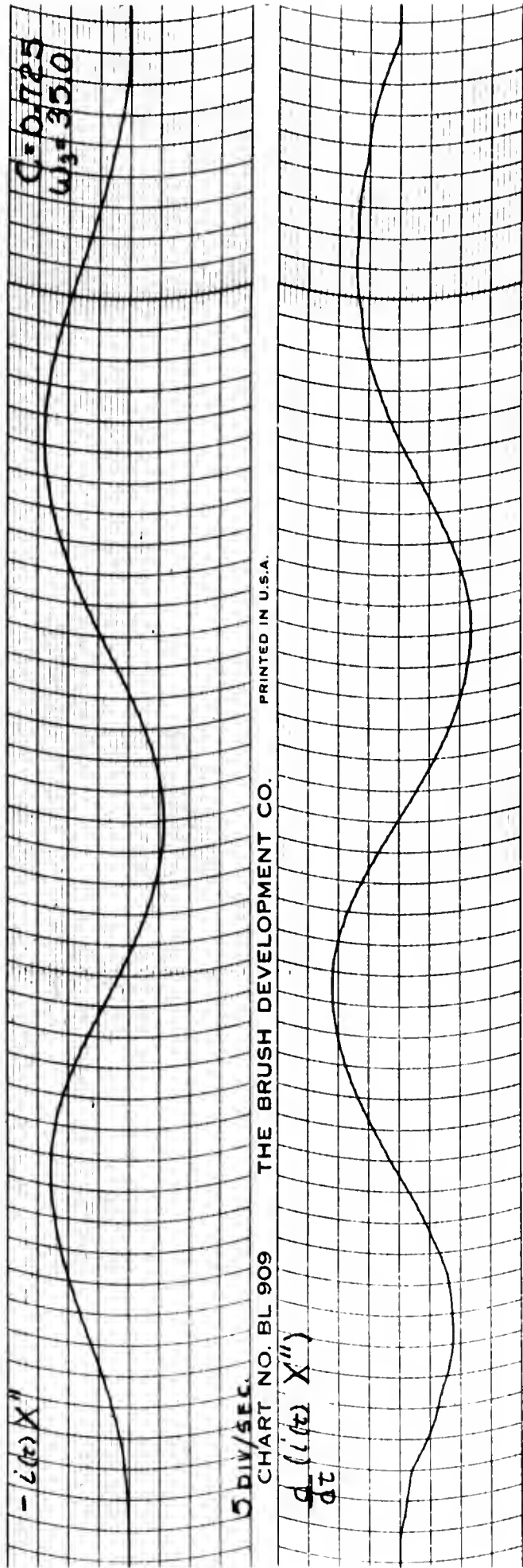


Figure 23

Oscilloscope Solution of Third Normal Mode, AFA 37,
Bending and Shear Deflections and Rotary Inertia.

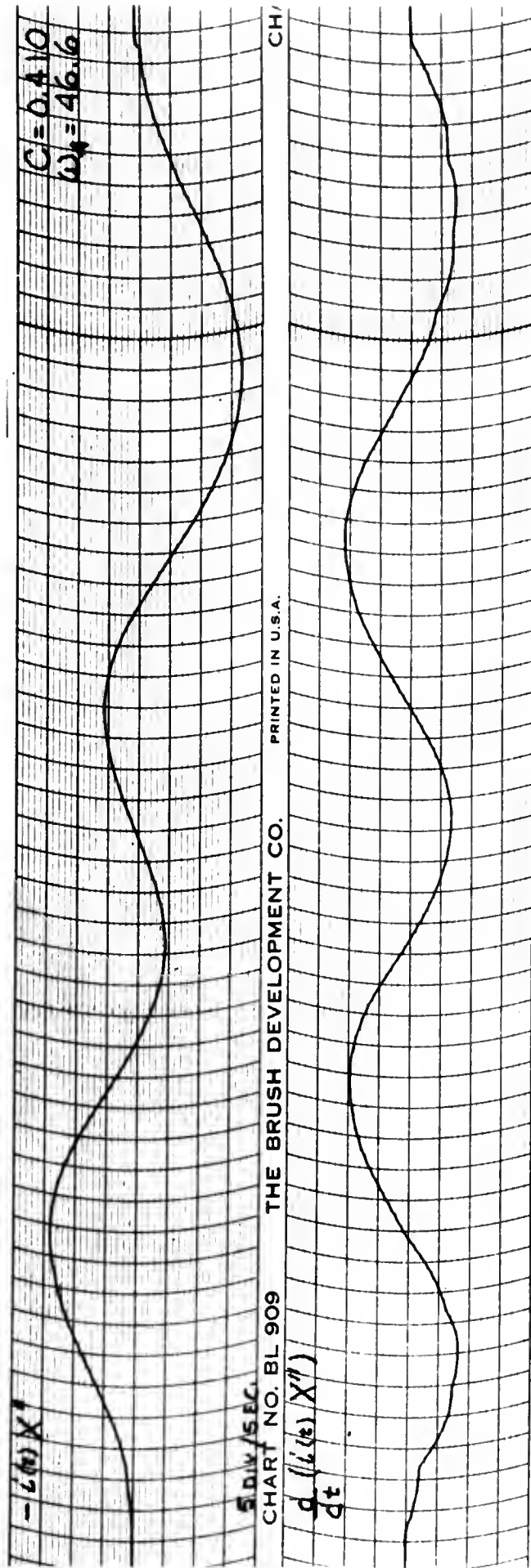


Figure 24

Oscillograph Solution of Fourth Normal Mode, APA 87,

Bending and Shear Deflections and Rotary Inertia.

Thesis

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analog computer...

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